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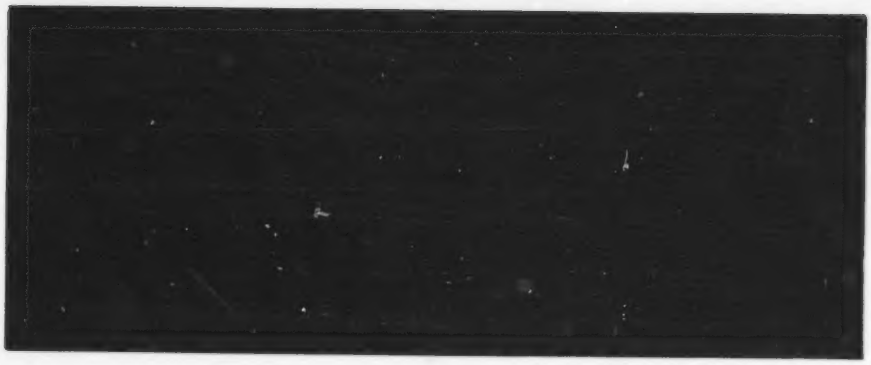

V-86-07-0029

A STUDY OF FACTORS AFFECTING PELLET DURABILITY AND PELLETING EFFICIENCY IN THE PRODUCTION OF DEHYDRATED ALFALFA PELLETS.

V-86-07-0029

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by

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SASKATCHEWAN DEHYDRATORS ASSOCIATION

March 1988

OBJECTIVES

The objectives of this study were to study factors affecting pellet durability and pelleting efficiency, and to determine methods by which each of these can be improved. The ultimate goal was to process a product more efficiently and to increase customer acceptance of a more durable product, thereby creating additional product demand.

EXPERIMENTAL APPROACH

An initial search of literature was conducted and discussions were held with specialists in the commercial field of equipment manufacturing. Following this, an industry monitoring study was conducted to identify parameters that affect pellet durability and pelleting efficiency. This study, would provide direction on the design of specific experiments using a commercial-scale experimental pelleting facility to more closely study those parameters identified to be important from the monitoring study.

Since there were no experimental facilities available, a decision was made to set up appropriate facilities on a commercial-scale basis. This was determined to be the most cost effective, and would yield information that could be directly applied to the industry.

RESULTS AND DISCUSSION

PART I - INDUSTRY MONITORING STUDY

Eight commercial pelleters representing a diverse range in equipment configuration were selected on the basis of capacity, pelleter die L/D ratio[1], die width, make of pelleter and number of rolls.

Pelleter operation was monitored on a regular basis over a period of one month. Samples of meal and pellets were collected for determination of moisture content, product quality and pellet durability.

Prior to undertaking the study, the prototype pellet durability tester developed last year was modified and evaluated. The purpose of this tester was to provide fast results and simulate actual handling and transport of pellets more closely (ie. provide more rigorous action on the pellets). The tester provided the desired results, and correlated very closely with the standard ASAE procedure.

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[1] L/D: Die thickness/pellet diameter

AGRICULTURAL DEVELOPMENT FUND PROJECT EXPENSE STATEMENT

PELLETER STUDY (V-86-07-0029)	Budget			Actual		
Date: 18-Mar-88	Jun/86-	Apr/87-		Jun/86-	Apr/87-	
Reporting Date: 29-Feb-88	Mar/87	to date	TOTAL	Mar/87	to date	TOTAL
1. Salaries & Benefits						
Dale Pulkinen	2,432	460	2,892	2,391	1,215	3,606
Brad Hill	6,988	290	7,278	7,305	6,697	14,002
Sub-total	9,420	750	10,170	9,696	7,912	17,608
Lab Tech	3,740		3,740	6,297	1,118	7,415
Gen labour	1,570		1,570	1,794	2,622	4,416
	14,730	750	15,480	17,787	11,652	29,439
2. Equipment						
Monitoring eqpt	100		100	430	200	630
Sample cooler	110		110	19	165	184
Pelleting facility	17,250		17,250	8,106	6,572	14,678
	17,460	0	17,460	8,555	6,937	15,492
3. Materials & Supplies						
Shop supplies, hdwe, etc.	300		300	5	47	52
Drafting supplies	100		100	75		75
Exptal mat (dies, screens, etc)	5,120		5,120	0	2,940	2,940
Lab supplies & misc	845		845	369	316	685
In-House analysis (@ cost)	1,800		1,800	2,375	2,148	4,523
Freight	350		350	0	1,291	1,291
L.D. Telephone	200		200	9	197	206
Sub-total	8,715	0	8,715	2,833	6,939	9,772
4. Travel						
In-house	350		350	117	(25)	92
Mileage & other	550		550	69	701	770
	900	0	900	186	676	862
5. Workshops/seminars						
Direct expenses	200	500	700	0	328	328
6. Overhead & Administration						
30% of labour	4,419	225	4,644	5,336	3,496	8,832
7. Other						
Sub-Contracts	13,350	0	13,350	5,439		5,439
TOTAL	59,774	1,475	61,249	40,137	30,028	70,165

ACKNOWLEDGEMENTS

This project was supported in part by Industrial and Regional Development Program - Regional Industrial Expansion and by Agricultural Development Fund - Saskatchewan Agriculture. Their support is gratefully appreciated.

EXECUTIVE SUMMARY

A study was conducted to investigate factors affecting the durability of alfalfa pellets and of pelleter operating efficiency. The goal of the study was to identify methods by which pellet durability could be improved and by which pelleter operating efficiency could be increased.

A monitoring study of commercial pelleters showed that die L/D ratio and conditioning temperature were the major factors affecting pellet durability. These findings were confirmed by subsequent experiments conducted on commercial scale pelleting equipment.

The findings of the commercial scale experimentation showed that, on average, pellet durability was improved by 30 - 35 percentage units when conditioning temperature was increased from 140 - 200°F. Pelleter power consumption was reduced from 36 Kj/lb at 160°F to 26 Kj/lb at 220°F; an improvement of almost 30% in pelleting efficiency.

There was no evident relationship between pre-conditioned (natural) meal moisture and pellet durability. Moisture level, on the other hand, affected pelleter operating efficiency. Power consumption was reduced by an average of 0.8 Kj/lb within the 3.5 to 8.0 percent moisture range of the test.

The quality of forage, meal bulk density and the use of pellet binding agents had no significant effect on durability or pelleter operating efficiency.

Studies on the processing of long fibre pellets showed that a larger hammermill screen size significantly increased the proportion of large fibre particles within alfalfa meal compared to traditional 1/4" pellets. However, the larger size of particles reduced the durability of large diameter pellets.

Factors affecting the durability of long fibre pellets were similar to those found in the 1/4" pellets; with meal conditioning temperature and pellet die L/D ratio being the most important. In addition, pelleter die speed reductions were necessary in order to successfully pellet with a larger diameter die. Pellet binding agents slightly improved the durability of the long fibre pellets.

DEFINITION OF PROBLEM

The alfalfa dehydrating industry has been marketing products to Japan since the early 1970's. It has since become our major market, where currently 75-80% of our product goes to that market. Our market share in Japan has increased steadily to where we now have approximately 75% of that market. However, the market size has not grown, but rather declined since the early 1980's. As a result, we have experienced situations of over-supply combined with low prices.

Within this general market situation in Japan is a change away from compound feed usage to that of direct feed usage, where livestock producers buy individual feed ingredients for on-farm mixing of their own rations. Associated with this change is the additional handling required to transport the product and the need to ensure that the product arrives intact when it reaches the farm.

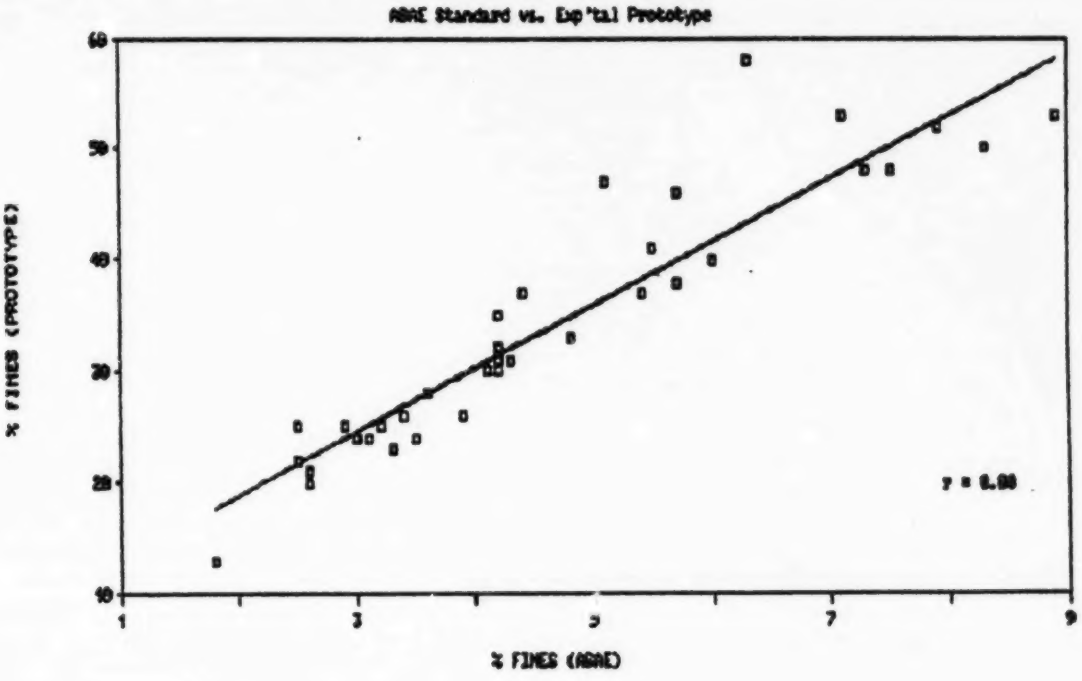
The problem with broken alfalfa pellets (fines) has become apparent by visual examination of our own product in Japan and by concerns expressed by Japanese buyers, merchandisers and inspection agents. It is not uncommon to find 20-30% fines in our product at the farm level; occasionally being as high as 50%.

With the current state of the industry, the trend has been to larger, more cost efficient manufacturing operations, who are attempting to process at near maximum capacity. This, however, has resulted, to some extent, in a less durable product.

Studies were conducted last year to attempt to overcome this problem. Various pellet binders were evaluated using the experimental facilities at POS Pilot Plant Corporation in Saskatoon. The findings were inconclusive due to problems associated with the pilot-scale equipment. However, they did suggest that some possibilities exist in the use of pellet binding agents as a means of increasing product durability. Evaluation under commercial-scale conditions appears to be the preferred method for obtaining reliable results.

Associated with the need for improving product durability is a requirement for efficient pelleter operation; since pelleting costs account for approximately 15% of total processing costs. Factors affecting pelleting efficiency and pellet durability as related to alfalfa processing are not clearly understood. A detailed study of these factors, followed by adaptation of any recommendations arising from this type of work will result in the improvements desired.

Figure 1: Comparison of prototype pellet durability tester with a standard ASAE tester.



Data obtained from industry monitoring was analyzed by step-down multiple regression using the following measured independant variables. Pellet durability was used as the dependant variable.

1) tonnes/hr/pelleter hp.
2) tonnes/hr/sq.ft. die surface area.
3) pelleter die L/D ratio.
4) distance gap between die rolls and die surface.
5) pre-conditioned meal moisture (dry chops moisture content).
6) pre-conditioned meal temperature.
7) conditioned meal moisture.
8) conditioned meal temperature.
9) forage protein content.
10) forage fibre content.

The best prediction of pellet durability was obtained using variables 3,5,8 and 10. The equation derived using these four variables is:

Predicted pellet durability (%) =

$$9.03 + 5.87(x_1) + 0.44(x_2) - 1.35(x_3) - 0.53(x_4)$$

where x_1 = pelleter die L/D ratio.
x_2 = conditioned meal temperature.
x_3 = product moisture before conditioning (dry chops moisture).
x_4 = forage fibre content.

Using the above equation, the correlation coefficient between predicted pellet durability vs. actual durability was 0.57. Inclusion of other variables into the equation reduced the coefficient.

Illustrations of the relationship between pelleter die L/D ratio and conditioning temperature on pellet durability are shown in Figures 2 and 3. These 2 variables were determined to be the major factors affecting pellet durability.

Figure 2: Effect of die L/D ratio on pellet durability.

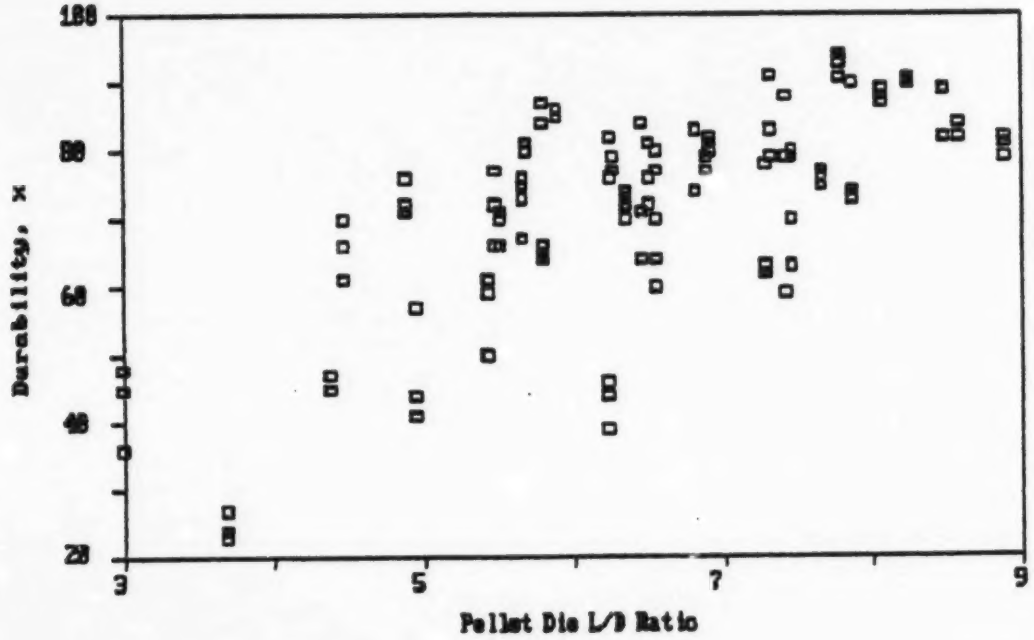
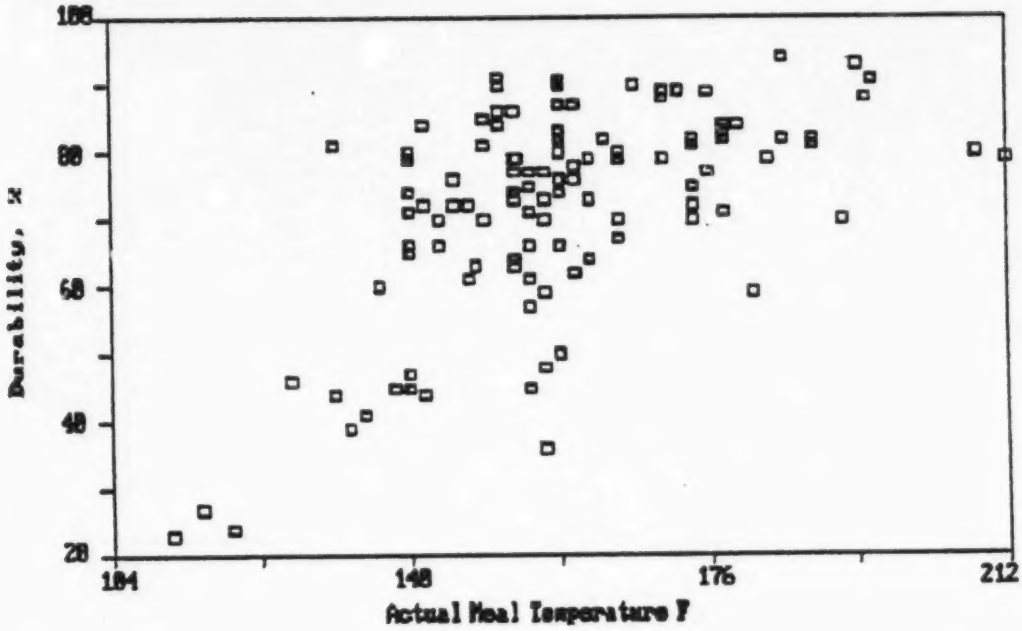


Figure 3: Effect of meal conditioning temperature on pellet durability.



Some problems in monitoring and sampling were encountered; partly due to physical constraints at two of the plants and partly due to inconsistent meal sampling procedures. Nevertheless, the study showed that die L/D ratio and conditioning temperature significantly affected pellet durability. On the average, increasing die L/D ratio from 5 to 9 increased durability from 50% to approximately 80%. When conditioning temperature was increased from 140°F to 190°F, pellet durability increased by the same magnitude. Other parameters had no apparent effect on pellet durability.

PART II - EXPERIMENTAL COMMERCIAL-SCALE STUDY

Based on the information obtained from the monitoring study, a series of experiments were designed to study factors affecting pellet durability and pelleter operating efficiency using the experimental commercial-scale pelleting facility. The major factors studied included:

1) dryer temperature (dry chops moisture content).
2) conditioning temperature.
3) meal grind size.
4) die configuration (L/D ratio).
5) pellet diameter.
6) pellet binding agents.

Studies included the following:

1) A series of replicated 3x4x2 factorial experiments where dryer temperature, meal conditioning temperature and die L/D ratio were varied.

2) Comparison of 1/4" vs. 11/64" pellet diameter using a similar experimental design as in 1) Only one L/D ratio was evaluated with the 11/64" diameter pellet since varying L/D ratio dies are not commonly available commercially.

3) Comparison of a coarse, medium and fine grind alfalfa meal at 3 dryer temperatures x 4 conditioning temperatures x 2 pellet diameters.

4) Evaluation of various commercial pellet binding agents.

In each experiment, the pelleter was fed under constant (maximum) loading. Samples of meal and pellets were collected, and pelleter function was monitored. Measurements included:

1) pellet durability.
2) meal and pellet moisture content and temperature.
3) pelleter throughput rate.
4) meal and pellet bulk density.
5) meal and pellet particle size distribution.
6) forage quality.

The conditioner in the experimental pelleter was modified to increase meal residence time. This allowed for more effective conditioning (ie. longer contact with the steam). This was accomplished by inserting a series of baffles to slow the rate of meal travel through the conditioner. Residence time increased from 15 seconds to approximately 45 seconds.

Conditioning Temperature

The findings of the commercial scale experimentation on the effect of conditioning temperature on the durability of pellets is illustrated in Figure 4. These results show that, on average, pellet durability was improved by 30 - 35 percentage units when conditioning temperature was increased from 140 - 200°F. They confirm the findings of the monitoring study, indicating the importance of maintaining a high conditioning temperature in order to produce a durable pellet. Data presented elsewhere in this report show additional data supporting these findings.

The aforementioned studies on conditioning temperature was conducted in 1986, and rudimentary measurement of pelleter power usage was not considered satisfactory. A portion of the work was

repeated in 1987, and the average results are presented in Figure 5. Pellet durability was again improved with higher conditioning temperatures, and pelleter power consumption was reduced from 36 Kj/lb at 160°F to 26 Kj/lb at 220°F; an improvemnt of almost 30% in pelleting efficiency.

Figure 4: Effect of conditioning temperature on pellet durability (1986 study).

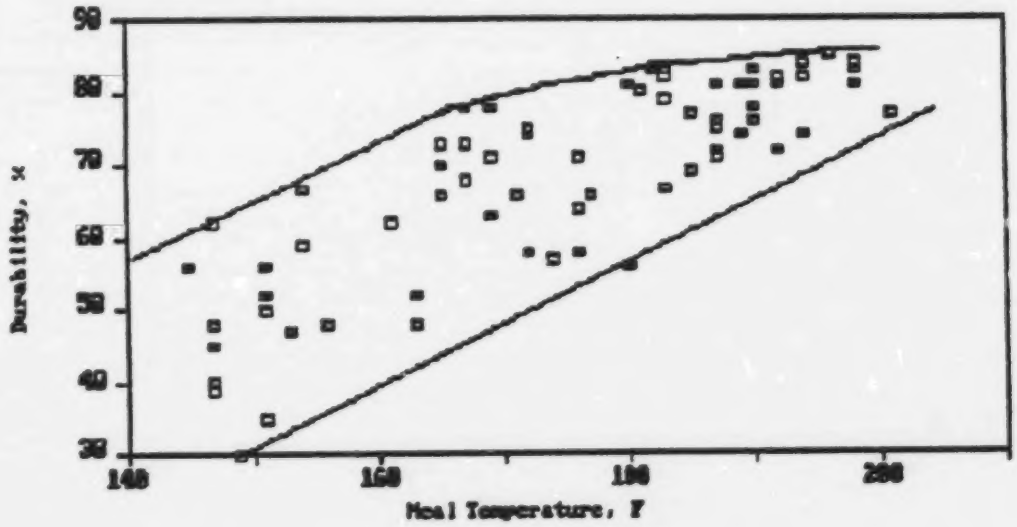
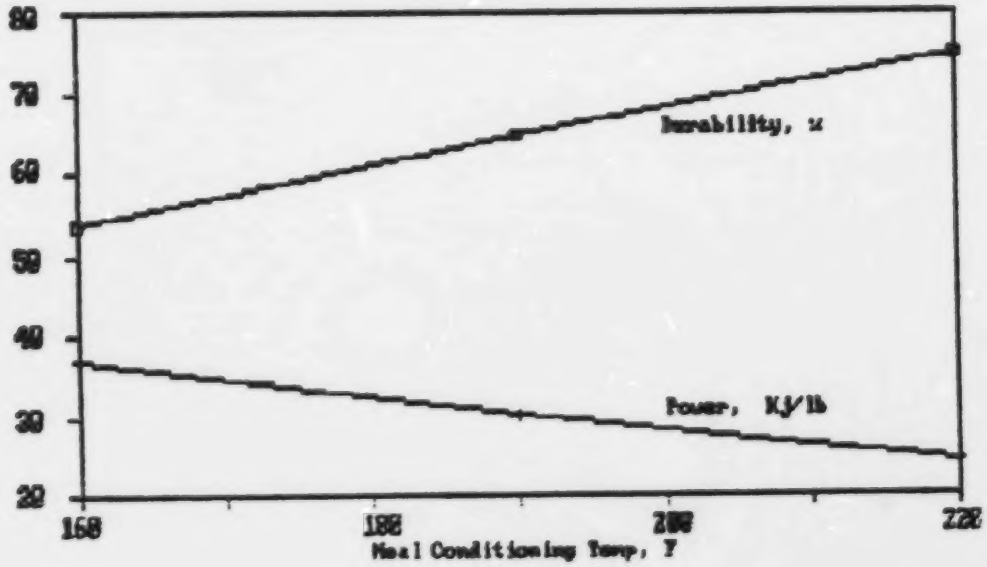


Figure 5: Effect of conditioning temperature on pellet durability and pelleter operating efficiency (1987 study).



Die Thickness (L/D Ratio) and Pellet Diameter

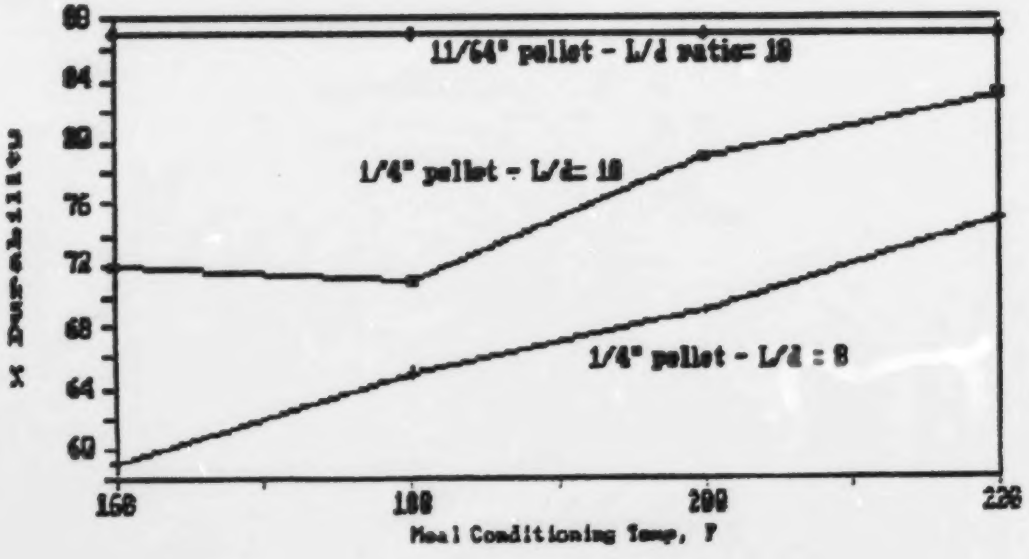
Figure 6 compares the effect of two pelleter dies with an L/D of 8 and 10 on pellet durability over a range of conditioning temperatures. These results represent an average of a number of tests conducted in 1986. They show that the 10 L/D die was approximately 10 percentage units higher in durability than the 8 L/D die, which was consistent throughout the entire range of conditioning temperatures used.

Although not illustrated, the range in pellet durabilities with the 8 L/D die was much larger at the lower conditioning temperature; whereas the 10 L/D die was more consistent. This suggests that a die with higher L/D will provide more consistent durabilities under a wide range of pelleting conditions.

The graph also shows a comparison between an 11/64" pelleter die and a 1/4" die. The 11/64" pelleter die was consistently higher in pellet durability than the 1/4" die over the entire range of conditioning temperatures studied. This improvement was approximately 15 percentage units at 160°F; whereas the difference was only approximately 5 percentage units when the meal was conditioned to 220°F. Additional studies are required to more fully evaluate the potential of smaller diameter pellets as a practical method of improving pellet durability.

Measurement of pelleter power consumption to determine effects on the efficiency of pelleter operation was not obtained due to the inaccuracy of the method by which electrical load was measured.

Figure 6: Effect of die L/D ratio and pellet diameter on pellet durability.



Forage Quality

Studies investigating the effects of forage quality showed that quality of forage *per se* had a negligible effect on pellet durability. Protein, however, had a notable effect on pelleting efficiency. An increase in protein content resulted in greater power requirements to produce a tonne of pellets. This is believed to be due to greater product dryness associated with higher quality. Higher protein forage contains more leaves, which are dried to a greater extent than stems. This, in turn, affects particle size, and is discussed in greater detail in a subsequent section.

Figure 7: Forage protein effect on durability and pelleting efficiency.

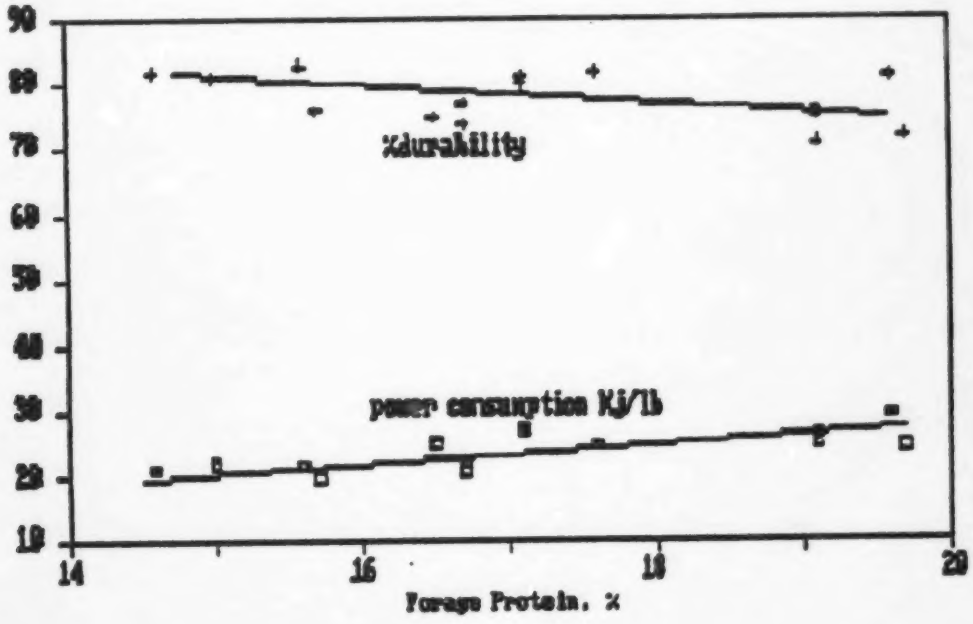
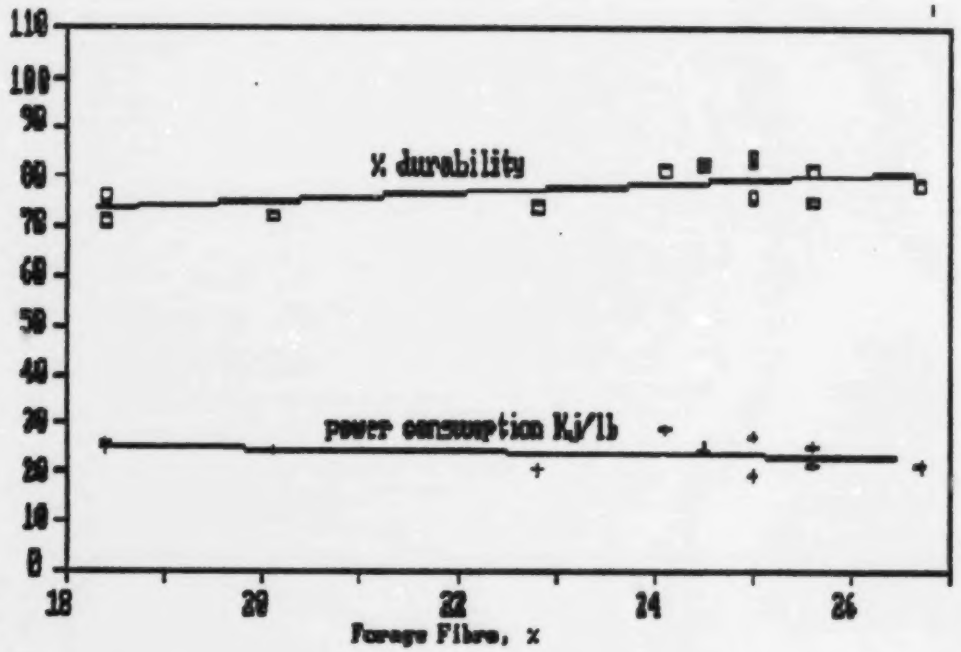


Figure 8: Forage fibre effect on durability and pelleting efficiency.

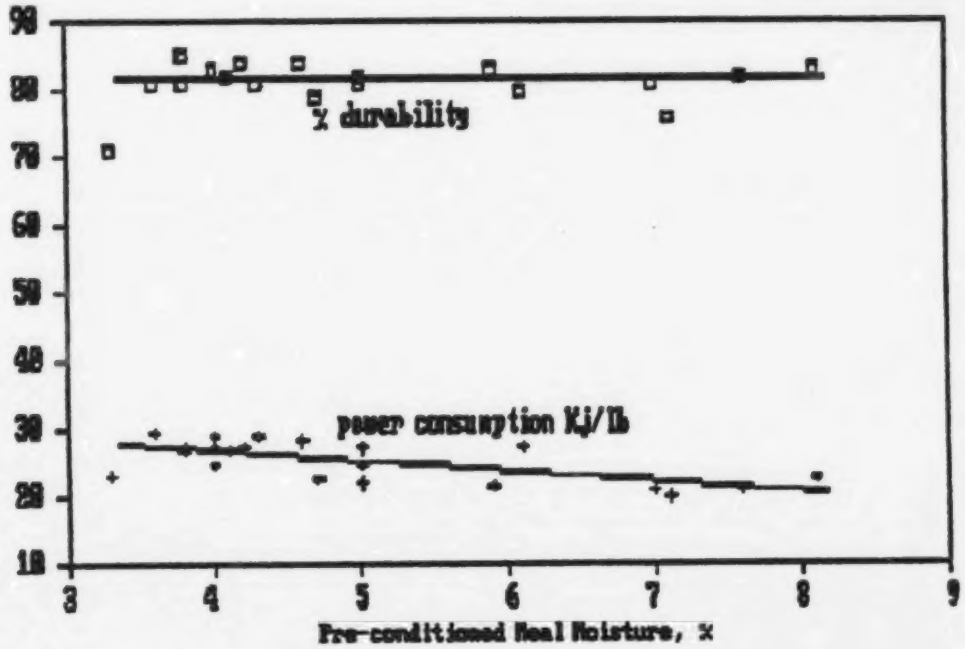


Meal Moisture

The moisture in the meal is in two forms: One is the natural moisture which is retained in the product after drying; while the other is the water added as a result of conditioning by the steam. Natural moisture is believed to be more important in any effects it might have in the specific parameters of interest in this study, since moisture added by conditioning is lost during pelleting and cooling. Further, moisture from the conditioning process constitutes only a small portion of the total moisture and is assumed to be insignificant. Our studies, therefore dealt only with the effects of natural meal moisture.

Studies showed that there was no evident relationship between pre-conditioned (natural) meal moisture and pellet durability. On the other hand, there was an improvement in pelleter operating efficiency as evidenced by the lower power consumption with higher moisture content. Power consumption was reduced by an average of 0.8 Kj/lb within the 3.5 - 8.0 percent moisture range of the test. The increased lubricity due to higher moisture meal is believed to be responsible for this.

Figure 9: Effect of natural meal moisture on durability and pelleting efficiency.



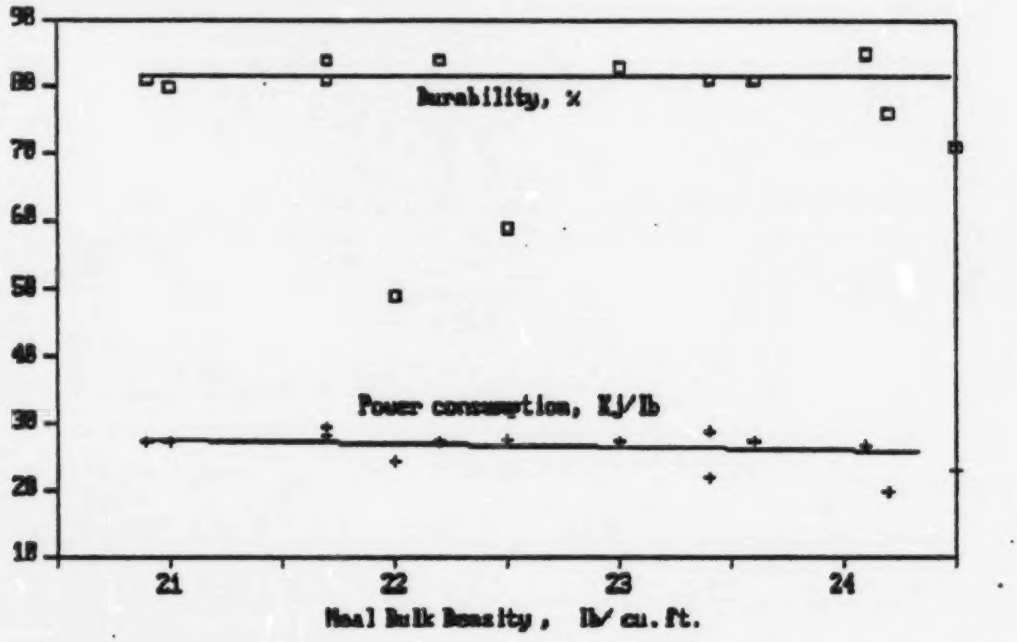
Meal Bulk Density

Meal bulk density had no effect on pellet durability, and pelleter production efficiency was improved only marginally as bulk density increased. On average, an increase of 1 lb/cu.ft. in meal density resulted in approximately 0.1 Kj/lb reduction in pelleter power consumption.

Although not specifically examined, it was felt that meal bulk density changes were attributed largely to maturity or fibre content of the alfalfa forage and in the distribution of particle size fractions within the meal itself. Examination of the data suggested a higher fibre content and a lower proportion of small particles associated with lower bulk density in the meal.

It would be desireable to determine if meal particle size distribution can be manipulated during processing to maintain high meal bulk density, and therefore, peak pelleter production efficiency.

Figure 10: Effect of meal bulk density on pellet durability and pelleter production efficiency.



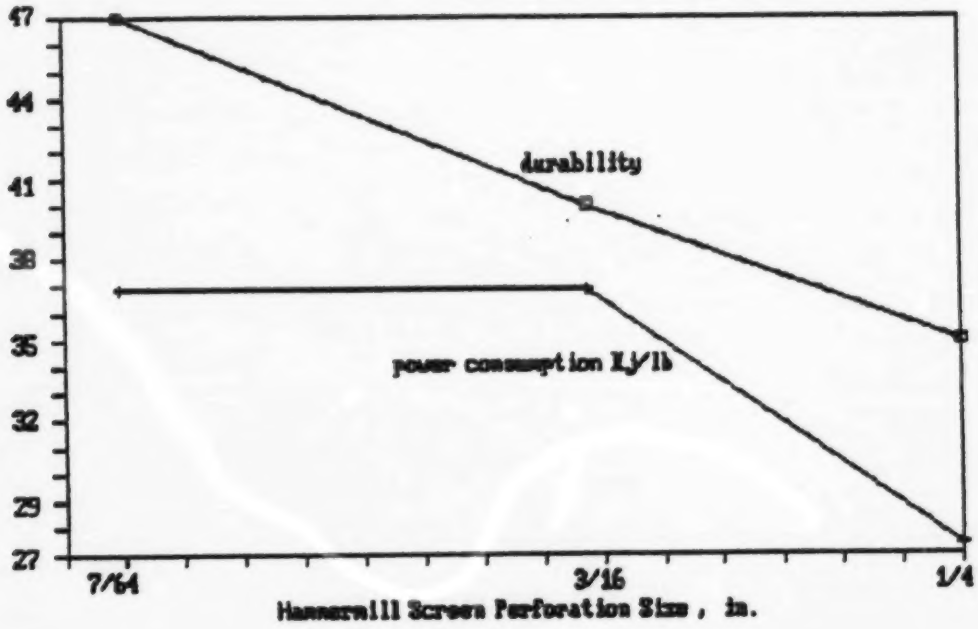
Particle Size

The alfalfa industry currently uses hammermill screens containing either a 7/64" or 1/8" hole size to mill the alfalfa in preparation for pelleting. As indicated earlier, particle size was thought to influence pelleter efficiency.

Studies were conducted to investigate the effects of particle size on pellet durability and pelleting efficiency. Hammermill screen sizes of 7/64, 3/16 and 1/4" were used to mill the dried alfalfa chops, which were then pelleted through a 1/4" pellet die.

Pelleting the various screen sizes of meal showed that pellet durability decreased with increasing particle size (Figure 11). Power consumption decreased as well, which is not surprising, considering the fact that lower energy input into the production of pellets resulted in lower durability.

Figure 11: Effect of meal particle size on durability of 1/4" pellets.



Pellet Binding Agents

Various commercial binders, including molasses and barley grain, were evaluated under commercial production conditions to determine their effectiveness as a pellet binding agent. The various agents used, their application rates and effect on pellet durability are given in Table 1. The results showed that none of the binders evaluated showed any improvement in pellet durability over the control.

Table 1: Effect of pellet binders on durability of 1/4" pellets.

Binding Agent	Application Rate (%)	Durability (% of Control)
Control	-	100
Bentonite	4	104
Perma-Pel (lignosulfonate)	1.5	96
Lignosite 458	1.5	94
Lignosite (neutr'ized, liq.)	4	96
Molasses (liquid)	4	93
Barley grain	40	100

Miscellaneous

Other observations noted, which were not a part of the initial study, included 1) a darkening of meal colour as conditioning temperatures increased from 160 to 220°F and 2) a tendency toward lower carotene content with higher conditioning temperatures. However, since pellets processed through the commercial-scale experimental facility did not receive antioxidant to protect the carotene, the resultant carotene values may not have been reliable.

PART III - LONG FIBRE PELLETS

During the course of the study, the project was expanded to cover a study on the production of long fibre pellets along the lines as outlined in Part II. The decision to proceed with this was based on a recommendation made in a report submitted to Saskatchewan Economic Dev't & Trade by Harvest Foods Ltd[2]. The report indicated that the demand for long fibre forages in the Japanese market was growing at a rapid rate, and that pellets with longer fibre length would be potentially siutable for that market. Since we already had the necessary experimental facilities in place that were ideally suited for conducting the work, it was only logical that the work be done.

The study investigated various pellet die configurations in combination with meal grind sizes and die speeds to determine effects on pellet durability and pelleter operating efficiency. In addition, binders were evaluated to determine their effect on pellet durability.

Due to some limitations in the availability of a wide range of pelleter dies, only a limited amount of comparative experimentation was conducted with pellet dies. Further, the dies that were available had certain design differences (ie. extrusion area, resistive surface area, etc.) which made comparative evaluation of specific parameters difficult. Consequently, some of the data presented herein represent a limited range in the various parameters studied. The various pelleter dies which were evaluated are presented in the following table.

Die No.	Extrusion Diameter (in)	L/D	Extrusion Area (sq in)	Resistive Surface Area (sq in)
1	1/4	8	96	3100
2	3/8	8	74	2400
3	1/2	8	69	2000
4	1/4	10	96	3800
5	1/2	10	85	3400

[2]The Processed Alfalfa Industry Market Assessment and Strategy for Development. March 1987. HARVEST FOODS LTD.

Hammermill screens consisting of 7/64, 3/16, 1/4, 3/8 and 1/2 inch screen hole size, including no hammermill screen, were used to produce meal that varied in fineness of grind. These were then pelleted through the above mentioned dies under various operating conditions.

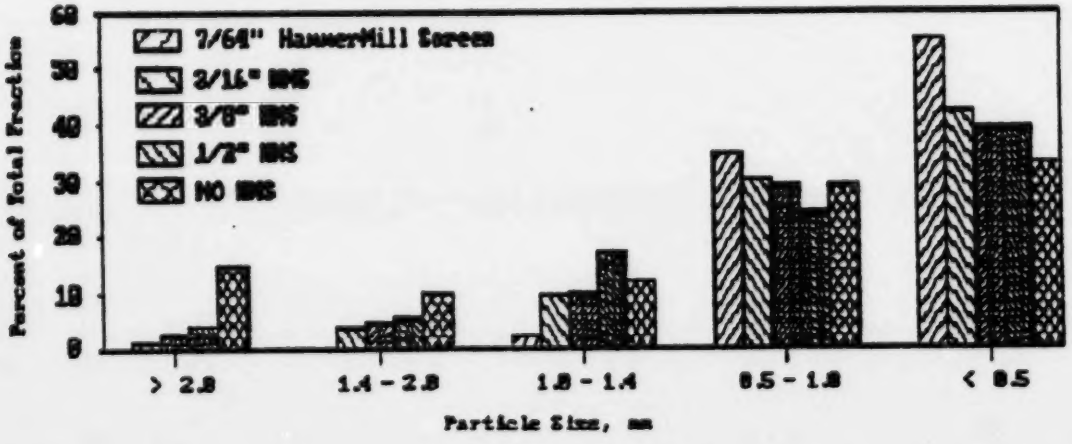
Particle size within the finished products were determined to compare their relative fibre length. This information would be used to assist in interpreting the results from the animal feeding trials scheduled for the 1987/88 winter at the University of Saskatchewan. These trials will be comparing conventional 1/4" pellets, appropriate meal grind sizes of either 3/8 or 1/2" long fibre pellets and cubes; with long hay as the control source of fibre. The feeding trials will include both dairy production and heifer growth trials.

Milling Effects on Particle Size

The initial work consisted of milling dried alfalfa chops through various screen sizes to determine the effect on particle size. The results of that work is summarized in Figure 12. The data shows a general increase in particle size within the larger fractions and a corresponding decrease in the smaller fractions as hammermill screen size is increased. Changes in the middle fractions were not as evident.

The results indicated that coarse grinding of the meal could be a practical method in achieving a significant change in the amount of long fibre present in alfalfa meal. Although the portion of long fibre is still lower than the material normally used for processing cubes (ie. no hammermill screen), there was sufficient promise to warrant continued work on developing the processing technology for the production of long fibre pellets.

Figure 12: Meal particle size distribution for various hammermill screen sizes.



Preliminary Pelleting Trials

Preliminary tests using various combinations of meal grind size and pellet diameter indicated that, for successful pelleting, the meal should be milled through a hammermill with screen hole size equal to or less than the diameter of the pellet. The exception to this was when the alfalfa forage was of very high quality (ie. low fibre content), in which case dried alfalfa chops could be passed through a hammermill containing no screen without any significant pelleting problems. Further, the effects of meal moisture content had some bearing on the size of particles during milling, which would affect the success of pelleting.

A commercial pelleter normally operates at a die rotational speed of 375 rpm. In our tests, the installation of a transmission allowed evaluation of specific speeds ranging from 60 - 500 rpm.

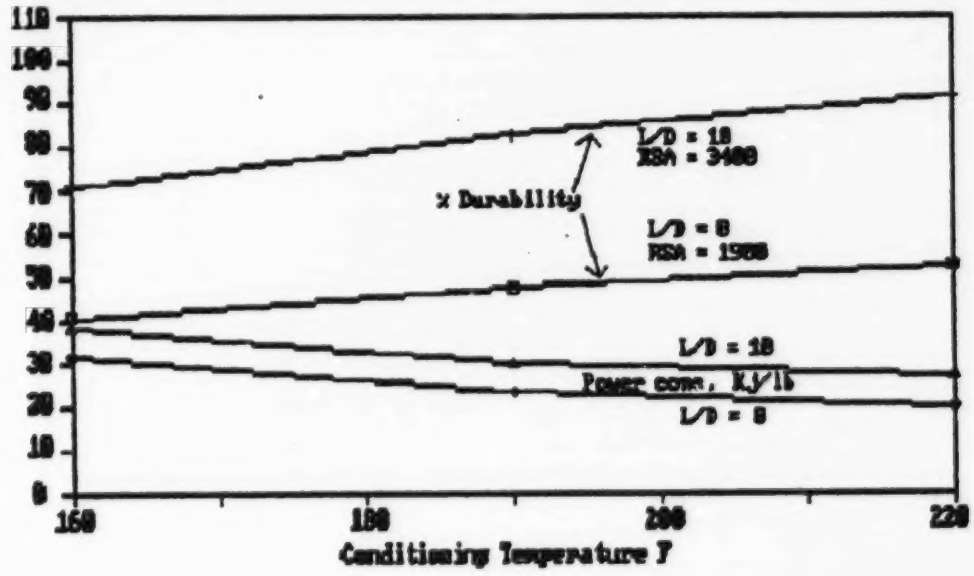
Trial and error experimentation with various die speeds using both 3/8 and 1/2 in. pelleter dies indicated that rotational speeds beyond the normal 375 rpm used in commercial pelleters were completely unsatisfactory. The axial force would result in longitudinal fragmentation of pellets and low pellet durability. Die speed of 344 rpm reduced the problem, but occurence of longitudinal cracking still occurred; although to a lesser extent. Speeds of 60 rpm, on the other hand, resulted in consistent plugging within the die cavity; as the slow peripheral speed would not keep the meal on the inside face of the die.

Occasional problems were experienced when meal was pelleted at a die speed of 125 rpm, particularly when the forage was high in fibre. We therefore concluded that the die speed in the production of long fibre pellets was limited to a fairly narrow range. Subsequent tests therefore conducted at 187 rpm, which was the only speed available, given the transmission installed on the pelleter.

Effects of Conditioning Temperature and Die L/D Ratio

Tests at various conditioning temperatures using the 8 and 10 L/D pelleter dies with a 1/2" pellet diameter showed similar results as found in the earlier work using 1/4" diameter pellets. The results (Figure 13) show the positive effect of maintaining high conditioning temperatures and the effect on increased pelleter operating efficiency. No comparative work was conducted on 3/8" diameter pellets due to the unavailability of a second die with a different L/D ratio.

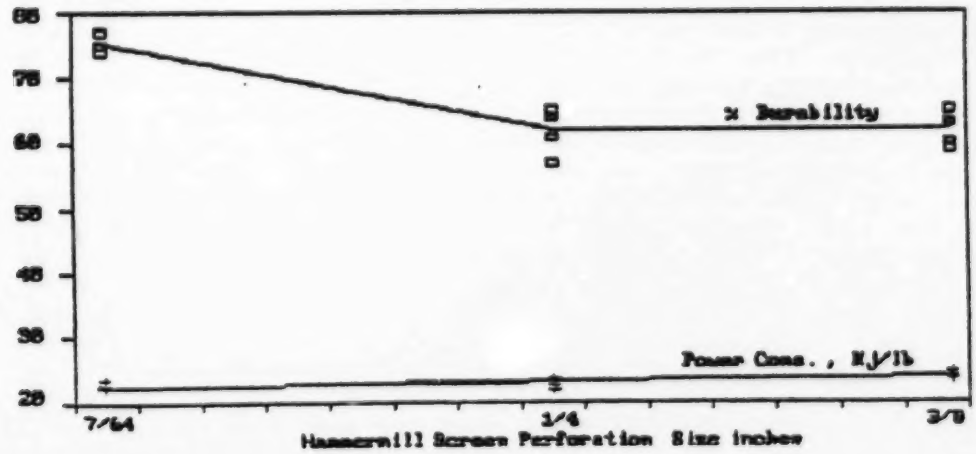
Figure 13: Effect of pelleter die design on pellet durability and production efficiency at various conditioning temperatures.



Effect of Meal Fineness on Pelleting

A series of tests were conducted using 7/64, 1/4 and 3/8 inch meal grind sizes to produce a 3/8" diameter pellet. The results of this are presented in Figure 14. They are similar to those found with the 1/4" pellets; where durability of pellets was reduced as particle sisze increased. On the other hand, there was no significant effect on pelleter operating efficiency.

Figure 14. Effect of meal grind size on pellet durability and pelleter operating efficiency.



Pellet Binding Agents

A limited number of pellet binding agents were evaluated to determine their effect on pellet durability for 3/8" diameter pellets. The results of those trials are given in Table 2. The effect of binders with the 3/8" pellets was somewhat more evident than for the 1/4" pellets. However, the level of improvement in durability was still marginal.

Table 2: Evaluation of pellet binders on 3/8" pellets.

Binding Agent	Application Rate (%)	Durability (% of Control)
Control	-	100
Bentonite	3	107
Perma-Pel (lignosulfonate)	1.5	97
Lignosite 458	1.5	110

Preparation of Products for Feeding Evaluation

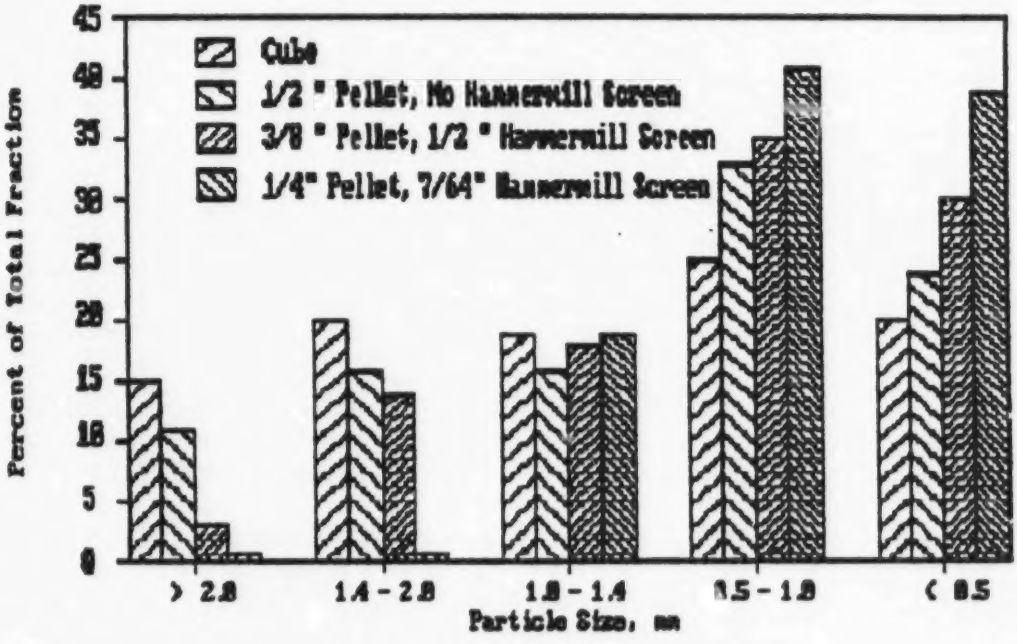
Towards the end of the production season, four lots of products were prepared from the same raw material for the feeding trials scheduled for the University of Saskatchewan. The final products selected included 1/4" pellets, 1/2" pellets and cubes; with baled hay as the control.

Figure 15 shows the particle size distribution of the specific products processed for the trial, including typical 3/8" pellets that were analyzed during the course of the studies. The 3/8" pellets were not used in the feeding trials, but are presented for comparative purposes.

Since the raw material used was taken late in the production season, the quality of the material was higher than average dehy. Consequently, we did not have to use a hammermill screen when pelleting the 1/2" pellets.

Each product selected will be fed to lactating dairy cows at 4 kg/d in a switchback design. The balance of the forage component of the ration will consist of grass hay supplied by the University. Data will be collected on milk yield and composition, body weight changes, feed consumption and digestive disorders. A 2nd trial will compare the products in heifer growth trials. Preliminary results are expected in April/88.

Figure 15: Particle size distribution for various processed alfalfa products.



Pellet Die Design Comparisons

As indicated before, only a limited range of dies were available to conduct comparative studies on various die configurations. Data that was accumulated for each die used during the course of the study is summarized in Table 3.

In this table, L/D ratio is the ratio of die thickness:hole diameter. Extrusion area (EA) is defined as the total surface area of the interior die face which consists of holes. Resistive surface area (RSA) in a pelleter die is defined as the total surface area which provides resistance when the alfalfa meal is extruded through the die.

Factors important in achieving optimum durability and pelleting efficiency in the production of long fibre pellets were similar to those found for 1/4" pellets. These included meal conditioning temperature, pelleter die L/D ratio and fineness of meal. Additionally, pelleter die speed reductions were required in order to produce a satisfactory pellet.

Pellet binding agents offered a small level of improvement in the durability of long fibre pellets.

RECOMMENDATIONS

The recommendations made, in order of priority, as a result of the findings of this study are as follows:

1. Alfalfa meal for pelleting should be conditioned to a temperature of at least 200oF. More effective conditioning (absorbance of heat by the steam) can be achieved by not overdrying the alfalfa forage during dehydration.

2. Pelleter dies should have an L/D ratio of 10 to optimize pellet durability. A die producing 1/4" diameter pellets requires a thickness of 2 1/2" to meet the 10 L/D ratio; while a 3/8" and 1/2" die requires a 3 3/4 and 5 inch thick die respectively.

3. If fineness of grind is not important from a consumer/nutritional point of view, consider utilizing a hammermill screen with a 7/64" hole diameter when producing a 1/4" pellet. This will maximize pellet durability with no detrimental effect on pelleter operating efficiency. For larger diameter pellets intended for long fibre markets, the major consideration is to use the minimum particle size that will achieve the desired fibre length for market demands.

4. Alfalfa should be dehydrated to levels containing no less than 8-9 % moisture; as this will improve the efficiency in usage of pelleter power consumption.

Other avenues available for the reduction of fines in product delivered to the customer include:

1. Screening the product prior to shipment to remove fines which are in existence in stored product.

2. Explore alternative shipping methods (i.e. containerization and/or packaging) which will reduce the handling impact on creation of fines during transport.

Table 3. A comparative summary of of various pelleter die configurations.

Extrusion Diameter (in.)	L/D	Extrusion Area (sq.in.)	Resistive Surface Area (sq. in.)	Specific Desnity (lb/ft3)	Bulk Density (lb/ft3)	Durability (%)	Power Consumption (kj/lb)
1/4	8	96	3100	85	44	66	24
3/8	8	74	2400	76	37	60	20
1/2	8	69	2000	74	34	35	18
1/4	10	96	3800	83	45	83	23
1/2	10	85	3400	84	39	65	27

$$\text{L/D Ratio} = \frac{\text{Die Thickness (in.)}}{\text{Hole Diameter (in.)}}$$

EA (sq. in.) = No. of Holes X Hole Diameter (in.).

RSA (sq. in.) = Hole Diameter (in.) X Die Thickness(in.) X No of Holes.

The major points to note in this table are as follows:

1). Pellet durability is a direct function of pellet die resistive surface area. Since RSA is largely dependant on die thickness, for practical purposes one can use die L/D as a measure of it's ability to process durable pellets.

2). Pelleter power requirements generally increase with increased pellet durability.

3). Pellets with higher specific density are generally more durable.

4). As pellet diameter is increased, the durability and bulk density of pellets is reduced.

CONCLUSIONS

1/4 " Pellets

A number of factors were identified to affect the durability of pellets and the efficiency of pelleter operation when processing dehydrated alfalfa pellets. They include meal conditioning temperature, pelleter die thickness (L/D ratio), fineness of meal.

Conditioning temperature and die thickness were the most important factors affecting pellet durability. By increasing conditioning temperature from 160oF to 220oF, an effective increase of approximately 15 percentage units were achieved. Similarly, pelleter power requirements were reduced from 37Kj/lb to 16Kj/lb; an increase of approximatley 30 percent in operating efficiency.

Increasing the pelleter die thickness from an L/D of 8 to an L/D of 10 increased durability by approximately 10 percentage units.

Coarser grind alfalfa meal generally reduced pellet durability. Studies showed that in increase in hammermill screen size from 7/64" to 1/4" resulted in a reduction of approximately 10 percentage points in durability (pelleting efficiency??).

Pellets which are smaller in diameter than the traditional 1/4" pellet were more durable. The effect on increased power requirements, however, was inconclusive due to the lower meal blk density used in processing the smaller diameter pellets.

Other factors studied were determined to have either a small or negligible effect on pellet durability and pelleting efficiency. These factors included primarily forage quality and meal bulk density.

Various commercial pellet binding agents were found to be ineffective in improving the durability of alfalfa pellets.

Long Fibre Pellets

Studies on the production of long fibre pellets showed that, given existing technology, it is more difficult to produce a pellet of comparable durability to a standard 1/4" alfalfa pellet. Without additional effort geared towards improving the durability of pellets, it appears likely that long fibre pellets will have to be transported by modes other than bulk shipment in order to prevent significant product breakdown into fines.

It is possible to increase the fibre length in long fibre pellets subtantially from the 1/4" pellets. The extent of this benefit from a nutritional point of view will be determined upon completion of the feeding trials currently underway.

APPENDIX

Table 1: 1986 Pelleter Monitoring Study Results.

Pelleter			Production Rate				Pre-condit. Meal		Post-condit. Meal		Pellets				Forage	Quality	
											Before Cooling		After Cooling				
Ident.	hp.	Die Area (sq.in.)	t/hr	t/hr/hp	t/hr/in2	Die L/D ratio	Moist. (%)	Temp. (oF)	Moist. (%)	Temp. (oF)	Temp.	%H20	Temp.	%H20	Fiber (%)	Prot. (%)	Pellet Durability (%)
1 /1	250	347	7.5	0.030	0.022	3.7	9.7	102	9.3	115	172	11.3	86	9.4	23.8	14.1	27
1 /1	250	347	7.5	0.030	0.022	3.7	13.9	95	13.9	118	144	15.4	91	12.8	23.8	14.1	24
1 /1	250	347	7.5	0.030	0.022	3.7	12.3	93	14.2	111	140	12.6	91	11.5	23.8	14.1	23
1 /1	250	347	7.5	0.030	0.022	4.4	6.7	100	12.5	140	165	12.0	90	10.7	22.9	12.6	45
1 /1	250	347	7.5	0.030	0.022	4.4	7.4	100	11.7	138	167	11.3	88	10.5	22.9	12.6	45
1 /1	250	347	7.5	0.030	0.022	4.4	9.1	99	11.2	140	172	10.5	90	8.1	22.9	12.6	47
1 /1	250	347	7.5	0.030	0.022	4.9	9.1	86	11.1	154	172	9.8	88	9.7	24.2	14.2	71
1 /1	250	347	7.5	0.030	0.022	4.9	8.9	95	12.4	147	176	10.3	90	11.0	24.2	14.2	72
1 /1	250	347	7.5	0.030	0.022	4.9	9.7	95	10.5	150	178	10.3	88	7.5	24.2	14.2	76
1 /1	250	347	7.0	0.028	0.020	5.5	9.5	88	12.4	144	180	10.4	97	8.9	32.6	15.2	66
1 /1	250	347	7.0	0.028	0.020	5.5	12.0	104	12.0	140	176	11.6	97	8.9	32.6	15.2	71
1 /1	250	347	7.0	0.028	0.020	5.5	10.3	90	13.6	144	178	10.8	97	8.9	32.6	15.2	70
1 /1	250	347	7.5	0.030	0.022	5.9	7.6	111	9.0	153	199	9.2	100	8.3	21.5	16.0	86
1 /1	250	347	7.5	0.030	0.022	5.9	7.6	102	10.9	151	183	12.0	93	7.8	21.5	16.0	86
1 /1	250	347	7.5	0.030	0.022	5.9	7.5	111	11.0	149	181	10.6	100	8.0	21.5	16.0	85
1 /1	250	347	7.0	0.028	0.020	7.3	5.3	111	9.4	160	192	13.2	99	8.6	19.5	15.9	76
1 /1	250	347	7.0	0.028	0.020	7.3	8.9	111	10.4	160	196	11.4	99	8.2	19.5	15.9	62
1 /1	250	347	7.0	0.028	0.020	7.3	7.9	120	12.4	153	201	11.4	99	7.7	19.5	15.9	63
1 /2	300	490	7.5	0.025	0.015	4.9	10.9	97	14.0	135	185	14.8	91	11.5	23.8	14.1	41
1 /2	300	490	7.5	0.025	0.015	4.9	15.0	93	11.2	142	176	14.0	91	12.8	23.8	14.1	44
1 /2	300	490	7.5	0.025	0.015	4.9	7.9	108	9.7	154	198	14.9	86	9.4	23.8	14.1	57
1 /2	300	490	7.5	0.025	0.015	5.4	9.2	104	11.4	158	183	10.5	88	8.1	22.9	12.6	50
1 /2	300	490	7.5	0.025	0.015	5.4	10.7	104	12.3	156	174	14.0	90	10.7	22.9	12.6	59
1 /2	300	490	7.5	0.025	0.015	5.4	9.5	104	11.4	147	180	12.6	90	10.5	22.9	12.6	61
1 /2	300	490	7.5	0.025	0.015	5.8	8.0	111	10.6	153	181	13.4	86	7.5	24.2	14.2	64
1 /2	300	490	7.5	0.025	0.015	5.8	8.7	99	9.8	140	181	10.6	88	9.7	24.2	14.2	66
1 /2	300	490	7.5	0.025	0.015	5.8	10.8	97	10.8	140	183	9.6	90	11.0	24.2	14.2	65
1 /2	300	490	7.0	0.023	0.014	6.2	10.0	90	10.0	133	187	9.8	97	8.9	32.6	15.8	39
1 /2	300	490	7.0	0.023	0.014	6.2	9.2	111	11.7	131	190	10.5	97	8.9	32.6	15.8	44
1 /2	300	490	7.0	0.023	0.014	6.2	10.5	88	10.5	126	178	10.1	97	8.9	32.6	15.8	46
1 /2	300	490	7.5	0.025	0.015	6.5	5.7	111	10.4	149	149	10.2	93	8.3	21.5	16.0	81
1 /2	300	490	7.5	0.025	0.015	6.5	5.5	104	10.4	145	145	10.2	100	8.0	21.5	16.0	76
1 /2	300	490	7.5	0.025	0.015	6.5	5.7	104	11.0	145	145	12.0	100	7.8	21.5	16.0	72
1 /2	300	490	7.0	0.023	0.014	6.9	7.7	111	10.1	165	219	13.5	99	7.7	19.5	15.9	80
1 /2	300	490	7.0	0.023	0.014	6.9	7.0	115	10.7	189	216	12.6	99	8.2	19.5	15.9	82
1 /2	300	490	7.0	0.023	0.014	6.9	9.5	115	10.3	189	214	13.1	99	7.7	19.5	15.9	81
2 /1	150	220	4.0	0.027	0.018	5.5	7.4	117	9.8	158	187	9.5	102	6.8	22.4	14.4	66
2 /1	150	220	4.0	0.027	0.018	5.5	8.0	115	12.3	174	181	10.1	100	7.4	22.4	12.6	72
2 /1	150	220	4.0	0.027	0.018	5.5	6.4	115	10.1	154	180	9.0	102	7.9	22.4	12.6	77
2 /1	150	220	4.0	0.027	0.018	5.7	7.5	104	11.2	162	180	8.3	86	6.5	22.9	15.5	73
2 /1	150	220	4.0	0.027	0.018	5.7	6.1	104	6.1	158	178	10.0	86	6.2	22.9	15.5	76
2 /1	150	220	4.0	0.027	0.018	5.7	9.3	102	10.0	174	189	9.5	81	7.3	22.9	15.5	75
2 /1	150	220	4.0	0.027	0.018	6.3	6.5	117	11.2	158	185	8.3	95	8.2	23.4	15.5	74
2 /1	150	220	4.0	0.027	0.018	6.3	5.6	118	11.4	162	198	11.4	97	6.0	23.4	15.5	72
2 /1	150	220	4.0	0.027	0.018	6.5	6.6	109	7.2	162	190	11.2	91	8.9	27.1	12.9	64
2 /1	150	220	4.0	0.027	0.018	6.5	6.8	111	10.1	153	198	10.9	91	6.6	27.1	12.9	77
2 /1	150	220	4.0	0.027	0.018	6.5	7.0	111	11.3	165	201	11.8	91	9.7	27.1	12.9	70

Table 1: 1986 Pelleter Monitoring Study Results.

Pelleter			Production Rate				Pre-condit. Meal		Post-condit. Meal		Pellets				Forage	Quality	
											Before Cooling		After Cooling				
Ident.	hp.	Die Area (sq.in.)	t/hr	t/hr/hp	t/hr/in2	Die L/D ratio	Mois. (%)	Temp. (oF)	Mois. (%)	Temp. (oF)	Temp.	IN20	Temp.	IN20	Fiber (%)	Prot. (%)	Pellet Durability (%)
2 /1	150	220	4.0	0.027	0.018	7.5	6.0	117	8.6	183	210	8.9	84	7.8	17.5	18.1	79
2 /1	150	220	4.0	0.027	0.018	7.5	5.3	117	10.4	153	201	6.7	84	7.7	17.5	18.1	79
2 /1	150	220	4.0	0.027	0.018	7.5	4.7	115	10.0	208	217	11.7	84	8.3	17.5	18.1	80
2 /1	150	220	4.0	0.027	0.018	8.2	6.3	106	10.5	158	194	8.2	93	7.7	23.7	14.1	91
2 /1	150	220	4.0	0.027	0.018	8.2	5.6	106	11.1	151	176	9.1	93	6.3	23.7	14.1	90
2 /1	150	220	4.0	0.027	0.018	8.2	5.5	106	9.5	158	190	8.9	91	6.5	23.7	14.1	90
2 /2	150	220	4.0	0.027	0.018	5.7	4.3	108	6.1	165	169	9.3	84	6.5	22.9	15.4	67
2 /2	150	220	4.0	0.027	0.018	6.3	4.7	118	6.5	156	189	8.1	95	8.1	23.4	15.5	73
2 /2	150	220	4.0	0.027	0.018	6.3	6.1	113	11.4	149	194	7.2	97	6.0	23.4	15.5	70
2 /2	150	220	4.0	0.027	0.018	6.5	4.9	109	9.2	136	180	11.3	91	9.7	27.1	12.9	60
2 /2	150	220	4.0	0.027	0.018	6.5	5.6	111	8.9	140	194	7.2	91	6.6	27.1	12.9	80
2 /2	150	220	4.0	0.027	0.018	7.5	3.4	116	9.4	192	216	9.4	84	8.0	17.5	18.1	70
2 /2	150	220	4.0	0.027	0.018	7.5	3.4	114	8.5	174	216	7.9	84	7.6	17.5	18.1	70
2 /2	150	220	4.0	0.027	0.018	7.5	5.3	108	9.7	148	216	8.5	84	7.5	17.5	18.1	63
2 /2	150	220	4.0	0.027	0.018	8.1	8.5	106	9.1	160	194	9.4	91	6.3	23.7	14.1	87
2 /2	150	220	4.0	0.027	0.018	8.1	5.6	106	9.5	171	190	11.0	93	6.5	23.7	14.1	88
2 /2	150	220	4.0	0.027	0.018	8.1	5.3	102	9.3	171	201	8.9	93	7.7	23.7	14.1	89
2 /2	150	220	4.0	0.027	0.018	8.6	4.4	118	8.7	158	192	9.2	100	7.4	22.4	14.4	82
2 /2	150	220	4.0	0.027	0.018	8.6	5.0	122	12.5	180	185	8.4	102	8.0	22.4	12.6	84
2 /2	150	220	4.0	0.027	0.018	8.6	4.8	122	8.4	163	201	8.4	102	7.7	22.4	12.6	82
2 /3	250	415	8.0	0.032	0.019	6.2	5.0	118	13.1	174	205	13.2	95	9.0	23.4	15.5	82
2 /3	250	415	4.0	0.016	0.010	6.2	4.7	113	10.9	160	207	10.9	97	9.0	23.4	15.5	76
2 /3	250	415	8.0	0.032	0.019	6.5	5.0	111	12.5	178	199	10.1	91	9.6	27.1	12.9	84
2 /3	250	415	8.0	0.032	0.019	6.5	4.9	111	14.4	162	180	11.2	91	9.7	27.1	12.9	64
2 /3	250	415	8.0	0.032	0.019	6.5	5.6	109	11.3	178	199	11.8	91	6.6	27.1	12.9	71
2 /3	250	415	8.0	0.032	0.019	7.4	3.4	108	9.7	212	219	8.5	84	7.6	17.5	18.1	79
2 /3	250	415	8.0	0.032	0.019	7.4	5.3	114	9.7	195	210	8.5	84	7.5	17.5	18.1	88
2 /3	250	415	8.0	0.032	0.019	7.4	4.0	116	9.5	181	225	7.8	84	7.5	17.5	18.1	59
2 /3	250	415	8.0	0.032	0.019	7.8	5.4	102	8.5	194	207	8.2	93	6.8	23.7	14.1	93
2 /3	250	415	8.0	0.032	0.019	7.8	6.3	106	10.9	185	196	8.6	93	7.7	23.7	14.1	94
2 /3	250	415	8.0	0.032	0.019	7.8	7.4	106	12.1	196	208	9.8	91	7.4	23.7	14.1	91
2 /3	250	415	8.0	0.032	0.019	8.5	6.4	122	10.6	176	189	9.8	102	7.3	22.4	14.4	89
2 /3	250	415	8.0	0.032	0.019	8.5	4.8	118	11.5	172	185	10.4	100	7.9	22.4	14.4	89
2 /3	250	415	8.0	0.032	0.019	8.5	8.0	122	12.1	178	196	11.2	102	7.7	22.4	14.4	82
2 /3	250	415	8.0	0.032	0.019	8.9	9.9	108	8.2	162	198	8.2	84	6.5	22.9	15.4	79
2 /3	250	415	8.0	0.032	0.019	8.9	7.5	106	10.0	185	203	9.8	84	6.5	22.9	15.4	82
2 /3	250	415	8.0	0.032	0.019	8.9	8.3	108	10.4	174	192	8.6	81	6.2	22.9	15.4	81
3 /1	250	415	9.0	0.036	0.022	3.0	5.3	109	10.1	156	181	8.1	93	6.5	21.2	17.6	48
3 /1	250	415	9.0	0.036	0.022	3.0	6.4	109	9.9	154	187	8.5	95	6.3	21.2	17.6	45
3 /1	250	415	9.0	0.036	0.022	3.0	6.9	109	9.2	156	189	9.6	90	6.5	21.2	17.6	36
3 /1	250	415	9.0	0.036	0.022	5.7	6.1	111	11.8	165	174	11.8	82	8.0	23.5	12.1	86
3 /1	250	415	9.0	0.036	0.022	5.7	7.3	111	9.7	158	181	9.7	82	8.2	23.5	12.1	80
3 /1	250	415	9.0	0.036	0.022	5.7	5.8	111	8.8	131	158	9.5	82	8.1	23.5	12.1	81
3 /1	250	415	4.5	0.018	0.011	5.8	6.0	118	9.0	151	176	7.6	79	7.8	28.9	12.5	84
3 /1	250	415	4.5	0.018	0.011	5.8	5.9	111	10.0	158	167	8.9	81	6.6	28.9	12.5	87
3 /1	250	415	4.5	0.018	0.011	5.8	6.3	113	10.2	142	172	9.5	79	6.3	28.9	12.5	84
3 /1	250	415	4.5	0.018	0.011	6.3	12.5	104	9.7	153	181	9.8	84	7.7	27.4	14.5	79
3 /1	250	415	4.5	0.018	0.011	6.3	7.4	106	7.4	171	192	8.7	88	9.7	27.4	14.5	79
3 /1	250	415	4.5	0.018	0.011	6.3	7.3	106	9.7	156	176	9.8	86	7.5	27.4	14.5	77
3 /1	250	415	9.0	0.036	0.022	6.8	8.3	122	5.0	153	185	9.2	86	8.1	23.9	14.7	74
3 /1	250	415	9.0	0.036	0.022	6.8	8.5	122	11.6	140	187	11.6	86	8.1	23.9	14.7	74
3 /1	250	415	9.0	0.036	0.022	6.8	8.1	122	10.4	158	196	9.6	90	8.1	23.9	14.7	83
3 /1	250	415	7.0	0.028	0.017	6.9	10.8	115	12.1	154	176	12.6	79	8.6	19.7	15.3	77
3 /1	250	415	7.0	0.028	0.017	6.9	11.9	113	9.2	154	171	13.9	79	11.8	19.7	15.3	77
3 /1	250	415	7.0	0.028	0.017	6.9	5.8	99	9.3	140	178	15.0	79	7.4	19.7	15.3	79
3 /2	260	283	7.0	0.035	0.025	4.5	6.6	122	9.8	156	198	8.2	90	8.6	23.9	14.7	70

Table 1: 1986 Pelleter Monitoring Study Results.

Pelleter		Die Area	Production Rate			Die L/D	Pre-condit. Meal		Post-condit. Meal		Pellets				Forage	Quality	
											Before Cooling		After Cooling				Pellet
Ident.	hp.	(sq.in.)	t/hr	t/hr/hp	t/hr/in2	ratio	Mois. (%)	Temp. (oF)	Mois. (%)	Temp. (oF)	Temp.	%H2O	Temp.	%H2O	Fiber (%)	Prot. (%)	Durability (%)
3 /2	200	283	7.0	0.035	0.025	4.5	6.2	122	8.9	154	194	8.2	86	8.1	23.9	14.7	61
3 /2	200	283	7.0	0.035	0.025	4.5	9.7	122	9.7	154	198	9.7	86	11.8	23.9	14.7	66
3 /3	250	490	9.0	0.036	0.018	7.3	5.8	120	10.3	151	150	8.8	82	8.1	23.5	12.1	91
3 /3	250	490	9.0	0.036	0.018	7.3	8.1	120	11.5	165	176	11.0	82	8.1	23.5	12.1	79
3 /3	250	490	9.0	0.036	0.018	7.3	6.0	120	9.6	178	176	9.9	82	8.1	23.5	12.1	83
3 /3	250	490	7.0	0.028	0.014	7.7	6.3	122	10.5	154	196	6.6	86	8.6	23.9	14.7	75
3 /3	250	490	7.0	0.028	0.014	7.7	5.9	122	9.7	176	185	10.5	86	11.8	23.9	14.7	77
3 /3	250	490	7.0	0.028	0.014	7.7	6.0	122	9.6	158	194	10.1	90	7.4	23.9	14.7	76
3 /3	250	490	7.0	0.028	0.014	7.9	12.2	102	12.6	167	158	11.9	79	6.4	18.5	15.3	90
3 /3	250	490	7.0	0.028	0.014	7.9	12.9	111	12.9	158	154	10.1	79	6.5	18.5	15.3	74
3 /3	250	490	7.0	0.028	0.014	7.9	10.9	117	11.0	153	140	8.8	79	6.5	18.5	15.3	73
Average	229	366	6.5	0.028	0.018	6.4	7.4	109	10.4	158	184	10.3	90	8.2	23.3	14.7	72

Regression Output:

Constant			43.522									
Std Err of Y Est			9.378									
R Squared			0.661									
No. of Observations			114.00									
Degrees of Freedom			100.00									
X Coefficient(s)	-907.30	1241.84	5.52	-0.38	0.20	-0.40	0.36	-0.20	-0.10	-0.16	-1.72	0.41	-1.36	
Std Err of Coef.	453.91	663.00	0.87	0.51	0.14	0.64	0.08	0.08	0.62	0.16	0.74	0.37	0.73	